Quarterly report
Chronic Microelectrode Recording Array
NIH/NINDS
Period 04/01/06 – 06/30/06

Project: NIH/NINDS **Contract-No.** HHSN265200423621C
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Contact details:
Prof. Dr.-Ing. Florian Solzbacher, Ph.D.
Dept. of Electrical Engineering and Computing
Director Microsystems Laboratory
University of Utah
Department of Electrical and Computer Engineering
MEB 3280
Tel.: (801) 581 7408 / 6941 (secretary)
Fax: (801) 581 5281
Email: solzbach@ece.utah.edu
URL: http://www.microsystems.utah.edu

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I. Executive Summary

The overall goal of the contract No. NIH/NINDS HHSN265200423621C is to develop and test (in-vivo) a chronically implantable neural recording array and provide the device to the neuroscience community upon completion of the initial technical development phase for experimental use and evaluation.

The objective of the seventh contract quarter (Q7) as proposed was to:

a) Continue optimization of the backside metallization.
b) Implant further fully functional devices in a cat and acquire data for a month.
c) Continue improvement of design, construction, and testing of external interface components (i.e. power supply coil, forward telemetry transmitter, software controls, etc).
d) Gain experience in experimental procedures with wireless recording setup and compare data to benchmark system
e) Continue flip-chip integration work with addition of surface mount devices (SMDs) and custom made coil spacers to the integrated device.
f) Continue leakage current, impedance spectroscopy, adhesion and dissolution long term tests of SiC and Parylene encapsulation in buffer solution and subsequent further development of Parylene and SiC coating processes, materials characterization (material composition, electrical and chemical properties)
g) Conduct leakage current long term tests of the outermost mechanical protection layers of silicone, epotek.

Throughout the seventh quarter, all of the above mentioned objectives were completely accomplished with the exception of item c) which will be accomplished by July 12th, 2006.

II. Activity Summary

Key results for project period (Q 7) (work packages)

- <u>Fabrication of UEA test and hot chips</u>: fabrication of UEAs was continued. The Microsystems Lab continues to be in a production mode where new wafers are fed into the process every week. Work is in progress for optimizing fabrication processes and implementing wafer scale processes.
- <u>Development and fabrication of electronics and communications module:</u> The external interface circuits have been tested. The 2nd version signal processor has been tested. The interface is in use for the wireless recordings from cat cortex for the fulfillment of the contract requirements.
- <u>Development and fabrication of PI/BCB coil:</u> Design of the PI coils has been finalized and fully characterized. We have begun processing new wafers for coil production and a modified design that will allow placing of coils on the side of the processor instead of on top of the processor/array.
- <u>Flip-chip bonding and assembly:</u> A new concept of integrating the fully functional device is currently being designed and simulated
- <u>Hermetic encapsulation and layer coating:</u> The adhesion between parylene and the device materials has been tested. The leakage current test was performed on the mechanical protection layers.
- <u>Testing and validation of probe systems:</u> Wireless recordings have been carried out with chronically implanted interface since May 17th.

Meetings/presentations during project period (Q 7)

- Telephone conference with IZM
- Telephone conference with GVD Corporation, Cambridge, MA. Defined the workpackages in the collaboration to test the possibility of PTFE as the encapsulation material.

- Telephone conference with Dow Corning, Midland, MI. Initiated a collaboration to test the possibility of 'room temperature PECVD SiC' as the encapsulation material.
- Individual weekly project meetings of the project teams at the University of Utah as well as the subcontractors; meeting minutes are created in common format by all partners.

Patents (Q 7)

- Further processing of previously submitted invention disclosures. Initiation of patent search on neuroprosthetic devices to identify the profile for further invention disclosures, e.g. for the signal processor and coil design. The UofU Technology Commercialization Office is in the process of submitting five (5) patent disclosures worldwide.

Organizational accomplishments (Q 7)

- Defined the electrical and biocompatibility tests on PTFE based thin film layers. Provided by phone conference with GVD corporation, Cambridge, MA (phone conferences and Emails)
- Initiation of electrical and biocompatibility tests on 'room temperature PECVD SiC' film layers. Provided by phone conference with Dow Corning, Midland, MI. (phone conferences and Emails)
- Established and implemented protocols for good manufacturing practices and good laboratory procedures (GMP/GLP) in preparation of potential later FDA approval.

III. Research Results and Discussion

III.a. Probe system fabrication

III.a.1 Task 1 Fabrication of ultra thin Utah Electrode Array

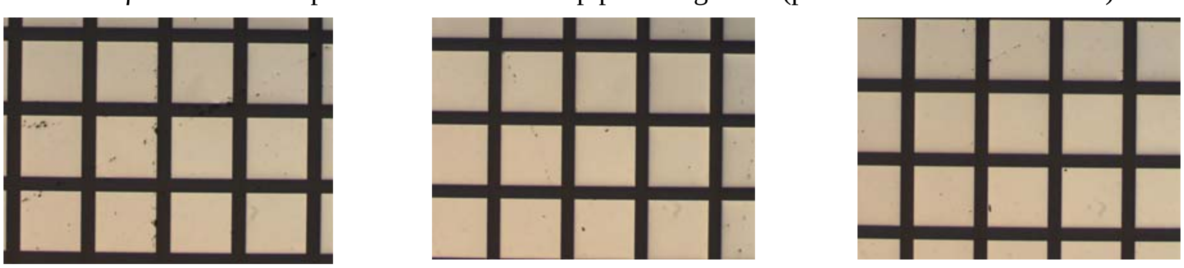
Description/Rationale

During the past quarter there have been several further improvements in the probe fabrication processes. The polishing process has been optimized. The metal adhesion on both backside and frontside of UEA has been characterized and equipment for waferscale etching has been built.

Experimental Results

Polishing: for the flip chip bonding process, the silicon to glass height difference should be less than 1 µm. The RMS roughness across the entire wafer should be less than 100 nm. During the past quarter, we have improved our manual polishing process and achieved a) a reduced glass to silicon height difference and a uniform surface roughness across the entire wafer compared to the conventional polishing process. An outline of the polishing process using Buehler Ltd., Lake Bluff, IL consumables is given below:

1. Polish on 240, 320, and 600 grit size silicon carbide polishing paper
2. 9 and 3 µm diamond suspension on hard perforated polishing cloth (part # Texmat AK8672)
3. 1 µm diamond suspension on medium nap polishing cloth (part # Microcloth AK7222)
4. 0.05 µm alumina suspension on medium nap polishing cloth (part # Microcloth AK7222)



Center Left Right

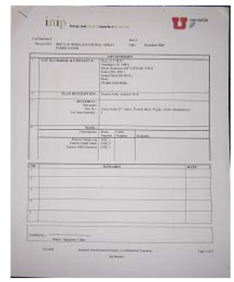
Fig. 1: Optical images at different locations on the wafer

Table 1: Measurements of surface roughness and Si to glass height across wafer

	Top	**Bottom**	**Right**	**Left**	**Centre**
Roughness (nm)	30	33	30	34	21
Silicon to glass height (nm)	+360	+400	+420	+390	+140

In Table 1, a "+" sign indicates that the glass is higher than the silicon surface. Although the obtained polishing results are acceptable for the flipchip bonding, we will continue to further reduce the silicon to glass height and RMS surface roughness in order to accomplish a close to standard SEMI surface quality.

Waferscale Etching: We are pursuing waferscale etching to increase through-put and to lower the cost of manufacturing UEAs. We have build a custom holder and etching equipment for waferscale etching.



Typical format used for UEA Process protocols

Fig. 2: Custom designed wafer holder for the waferscale etching

Fig. 3: Picture of process run sheet

GLP/GMP: In preparation of a future FDA approval, we have continued implementing good laboratory procedures (GLP (federal register 21 CFR part 58)) and good manufacturing procedures (GMP (federal register 21 CFR part 211)). Protocols are designed for materials, processes, and equipment used in the fabrication of UEA. The entire fabrication work has been segregated in four categories

1. Process run sheet for the neural array fabrication (Fig. 3): This document contains all the fabrication processes of the UEA and a copy of this sheet accompanies every wafer in the production.
2. Fabrication specification sheet: This document contains process recipe, it is intended to be a reference sheet for all the processes.
3. Material specification sheet: This document contains specifications of the materials used in the fabrication, including vendors and key properties of materials.
4. Work instruction sheet: This document contains minute details of a process. This is intended to help delegate a task to a new operator and for tech transfer.

Front Side Metallization: We have developed a new test for the adhesion of the tip metallization stack (Pt 240 nm /Ti 50 nm /Ir100 nm). Due to the topography of the arrays, it is difficult to conduct standard adhesion tests, such as ASTM tape and scratch tests. We have developed a novel method to check the adhesion of the metal on the tips. Utah Electrode Arrays (UEA) are poked into a PDMS film. The PDMS mimics the mechanical properties of cortical tissue, while exerting a high adhesive force. The vertical (insertion and removal) force is measured as a function of the (z-) displacement of the array. SEM micrographs are taken before and after insertion of the UEA for visual inspection of any change in surface topology. No metal disintegration was observed on the tips as seen in the SEM micrographs. The maximum force measured was 11.76N which exceeds the adhesion requirements for the tip metallization in tissue.

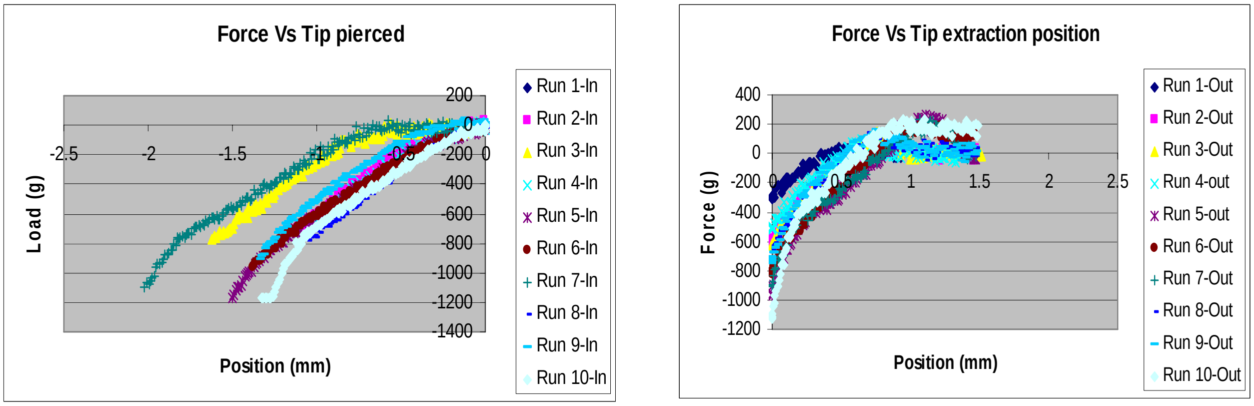


Fig. 4: Force applied to displace a UEA into PDMS (left), force applied to extracting the UEA from PDMS (right)

Iridium activation: To enhance recording stability and a safe range of charge injected during electrical stimulation, the active surface of the electrodes is metalized with iridium and then activated by the creation of an iridium oxide surface at the electrode interface. One method for performing this activation is to cycle the voltage at the electrode surface while the electrode is submersed in a conductive solution (cyclic voltammetry).

We have been successfully activating iridium tipped electrode arrays for all three chronic implants (for wireless recording) associated with this contract and we have additionally activated a number of other electrode arrays for further ongoing programs. As the activation process for a 100-electrode array lasts 72-hours (albeit not requiring constant supervision), we have examined alternative methods of activation. These include activating multiple electrodes simultaneously and using higher frequency activation cycles. We have found that the most reliable method of activation continues to be our original activation protocol of 1350 cycles of a ±1 Volt, 0.5 Hertz, triangle wave. We will continue to examine methods to reduce the time associated with activation. Additionally, we are redesigning the activation equipment to allow activation of 100 electrodes in one process, versus our present method of activating 25 electrodes in one process. Although this will not make the activation process any speedier, it will eliminate the need for 5-minute visits to the lab throughout the 72 hour activation process. Using four copies of the existing 32 channel circuit, we plan to activate all 100 electrodes in one process.

<u>Future Plan for Next Two (2) Quarters</u>

Design and build shear-testing equipment to have in-house capability to test the metal adhesion to the silicon wafer. About 20 finished arrays will be shipped to IZM for flip-chip bonding of the IC and the integration of SMD components. The wafer scale etching process will be characterized and optimized. A redesign the Iridium activation equipment to allow simultaneous activation of 100 electrodes is in progress.

III.a.2 Task 2: Development and fabrication of electronics and communications module

<u>Description/Rationale</u>

The electronics/communication module is a single CMOS integrated circuit mounted on the back of the microelectrode array. Three surface-mount capacitors mounted near the chip provide capacitance values not achievable on chip. The electronics module amplifies and processes neural signals, transmits this data out of the body on an RF carrier, and receives power and command data from the power coil via a transcutaneous magnetic link. For the purpose of the initial wireless recording experiments a hybrid solution that links wired UEAs to the RF communication platform was developed and is currently being used for wireless recordings from cat cortex.

Neural Recording and Wireless Transmission in Cat

We have been conducting experiments using the INI chips mounted on printed circuit boards (PCBs) to record and wirelessly transmit neural signals obtained in cat auditory cortex using a Utah Electrode Array (UEA). The UEA is connected via wires to a skull-mounted connector, and a board consisting of two INI chips is used to amplify, digitize, and transmit the data. It was necessary to use two chips due to digital noise from the A/D converter and other digital systems on the chip contributing high levels of noise to the low-noise biosignal amplifiers. A description of the two-chip system used to amplify and wirelessly transmit neural data from cat and the telemetered data is given in section III.b.1.2 (*In-vivo* testing of the interface) of this report.

Future Plans for Next Two (2) Quarters

We are planning the design of the next generation INI3 chip. Our goal with INI3 is to solve the digital noise problems seen in INI1 and INI2. We have also recently (June 21) identified the source of the power-up problem in the INI2 chip, and this will be corrected on INI3 so that it may be powered wirelessly.

III.a.3 Task 3: Development and fabrication of PI and BCB coils

Description/Rationale

Au coils on PI are manufactured and tested. A double layered coil with 51-turns in each layer, 20 µm width, and 15 µm spacing was selected to be used for the wireless device.

Future Plans for Next Two (2) Quarters

More fully assembled functional modules will built and powered using the PI based coils. Furthermore, we are designing an additional coil version that will place the coil next to the UEA rather than on top, while using the same electrical interconnects (bondpads).

III.a.4 Task 4: Flip-chip bonding and assembly

Description/Rationale

The single chip AuSn bumping is in progress. University of Utah sent the fabricated arrays with new metallization scheme to IZM. The assembly process was tested using these arrays.

Experimental Results

Ti/Pt/Au Metallization: An external source was selected for the deposition of a new metallization scheme on the array wafer. Two 3” array wafers (060205A, 060221B) with Lift-off resist provided by the University of Utah were sent to the company MSF, Germany, for sputtering TiPtAu (layer sequence:100nm Ti, 200nm Pt, 150nm Au). Wafer 060205A was taken for testing. The wafers were sent back to the University of Utah after processing.

Assembly of the package: During the underfill and cure process the assemblies were fixed in the brass carrier. The dispense temperature for best flow properties of the underfill had to be adapted to the geometry and thermal behavior of the array and the carrier. With these optimized process parameters a complete and void free underfill was achieved for all assemblies. The acoustic microscopy images of three assembled modules in Fig. 6 show no air entrapments or delamination.

Discussion/Interpretation of Results

The arrays sent by University of Utah were used to successfully setup the assembly process. The Au/Sn electroplating process for the single chip bumping is in progress.

Future Plans for Next Two (2) Quarters

Arrays with other pad metallizations will be tested at IZM with respect to crack formation and adhesion of the metal layer. Redesigned ICs will be AuSn single chip bumped. A further optimization of the bonding process of the coil/ferrite on the package will be performed. Finally functional sensor packages will be assembled.

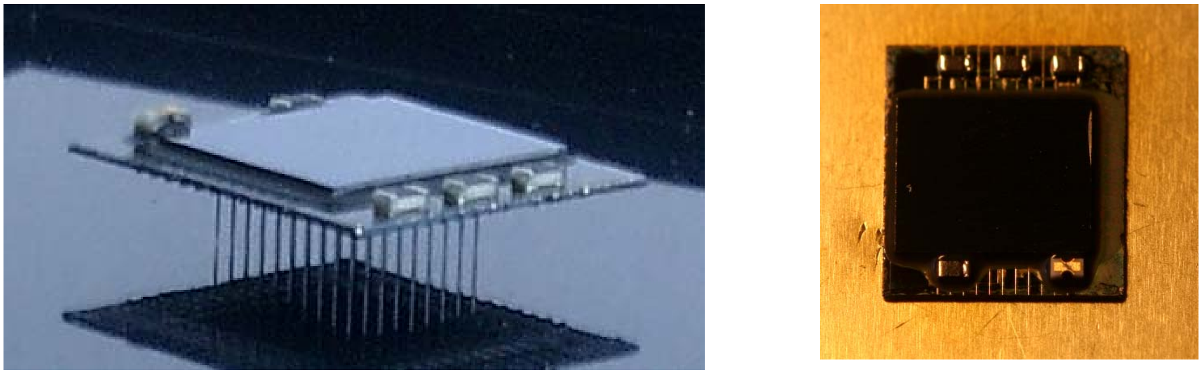
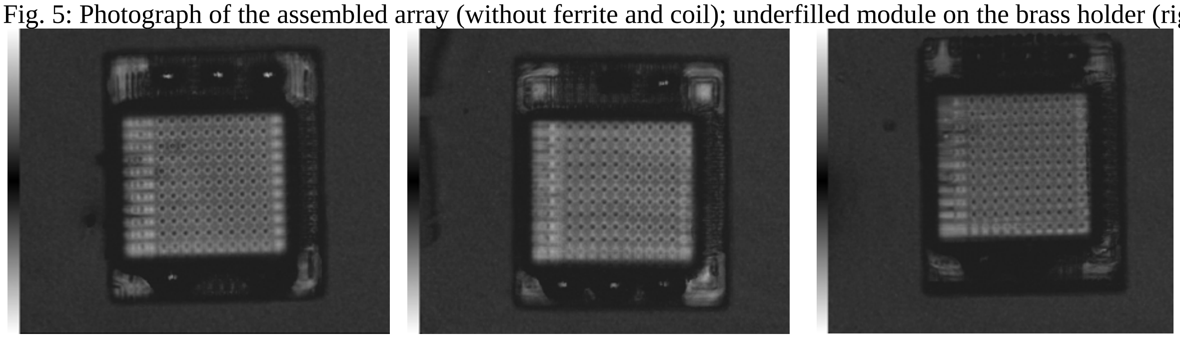


Fig. 5: Photograph of the assembled array (without ferrite and coil); underfilled module on the brass holder (right)



Module 12 Module 13 Module 14

Fig. 6: Acoustic microscopy images from module 12, 13 and 14.

III.a.5 Task 5: Hermetic encapsulation and layer coating

<u>Description/Rationale</u>

In this quarter some modifications of the sample preparation setup of the leakage current test system were implemented. The round PCB part of the sample bottle cap was modified by using a new design shape of the contact area for the contact pins of the multiplexer electronic (Fig. 7). The former top material layer of soldered thin was changed to gold metallization which provides a more precise geometry of the surface and prevents possible corrosion effects. Another change was made with a new IDE sample design to optimize the sample preparation and to reduce possible failures caused by the use of PTFE wires (Fig. 8). For this the changed ceramic shape can be attached directly to the new PCB.

Fig. 7: Former PCB layout with soldered thin top layer (left) and new PCB with changed shape and gold top layer (right).

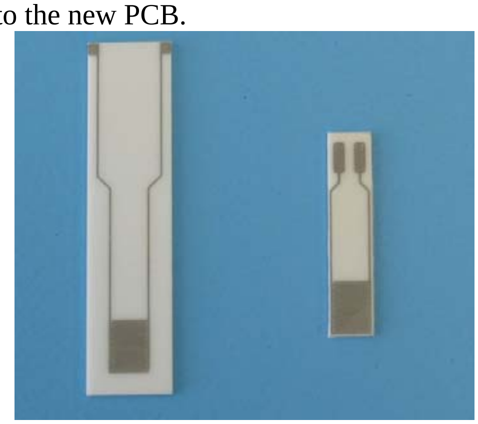


Fig. 8: Standard IDE structure on ceramic (right) and new test structure for better test performance (left).

Leakage current measurements were carried out for the evaluation of encapsulation properties of silicones and epoxy resins as mechanical protection layer of the coated parts of the array (transducer area). In contrast to gas deposition processes like SiC- or Parylene coating silicones and epoxies has to be processed in a liquid phase. So an injection moulding technique was developed as described in a former report to achieve well defined structures with the embedded IDE samples. For better process ability of the injection moulding application an IDE with PTFE wire attachment was used.

The ceramic based samples were fixed inside the moulding and filled with the used silicones and epoxy resins (Fig. 9). Focus of this investigation was the use of two medical grade silicones (MED 1137 and MED 2000, Polytec GmbH, Germany) and two medical grade epoxy resins (Epotek 310 and Epotek 354, Polytec GmbH, Germany). Five samples were used for tests of each material (Fig. 10). The whole system was heated up to 37 °C to mimic the physiological environment. To simulate an average operating voltage, a voltage source with 5 V DC was used. The sealed IDE structures were immersed in physiological solution (0.9 % NaCl) inside the sample bottle. All encapsulated structures were investigated for about three days without solution to detect possible failures during the assembling process.

Fig. 9: Injection moulding made of PTFE with fixed IDE ceramic sample and bottle cap.

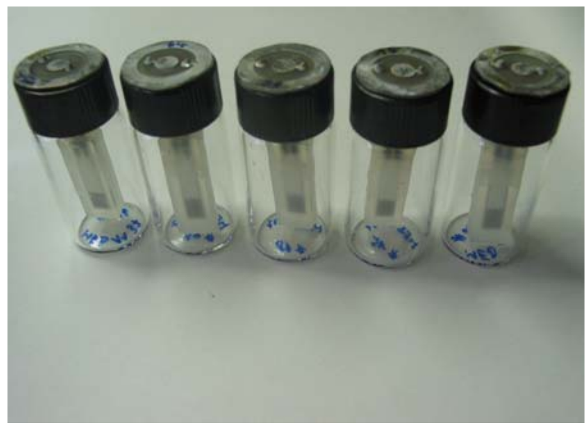


Fig. 10: Five prepared sample bottles with encapsulated ceramics (MED 1137).

After three days, the sample bottles were filled with physiological solution which was preheated to 37 °C. After 33 days (30 days in physiological saline solution) of testing the sample bottles were taken out of the measurement system to inspect the test structures and encapsulation areas via light microscopy.

Additional tests were made with a 90° peel test of Parylene C layer on a silicon surface with dry application of a silane adhesion promoter. For this, a silicon wafer was coated with 15 µm Parylene C at the University of Utah. Before coating the wafer, the surface was treated with an oxygen plasma, following dry application of A-174 silane adhesion promoter.

The coated wafer was then diced into several pieces with 5 mm width for 90° peel tests which were performed on a tensile strength machine. A small part of the film was coated on a separating layer (glue tape) on the wafer to have a free standing film for fixing it in the testing machine. The remaining part of the Parylene C film adhered on the Si wafer.

<u>Experimental Results</u>

The measured current of the samples for the first three days (try test and determination of upper limit of impedence values) was about 10^{-13} A to 10^{-11} A (Fig. 11). Only the Epotek 310 encapsulation showed a relatively high current of about 10^{-9} A in this first period. After 33 days of testing, MED 1137 and MED 2000 as well as both epoxy resin samples showed an increase of the current directly after filling with saline solution. For MED 1137 (80 % of the samples), the current increased very fast to 10^{-3} A which was defined as defect. MED 2000 reached a stationary value at about 10^{-9} A whereas some other samples increased their current till 10^{-5} A. For all Epotek 310 samples the current increased after a few days in solution up to a maximum value of 10^{-3} A, visual inspection showed corrosion of the IDE structures beneath the protection layer. Samples with Epotek 354 encapsulation showed low currents after filling of the solution, except one sample which increased its current up to 10^{-8} A. The other samples followed this behaviour after about 15 to 20 days.

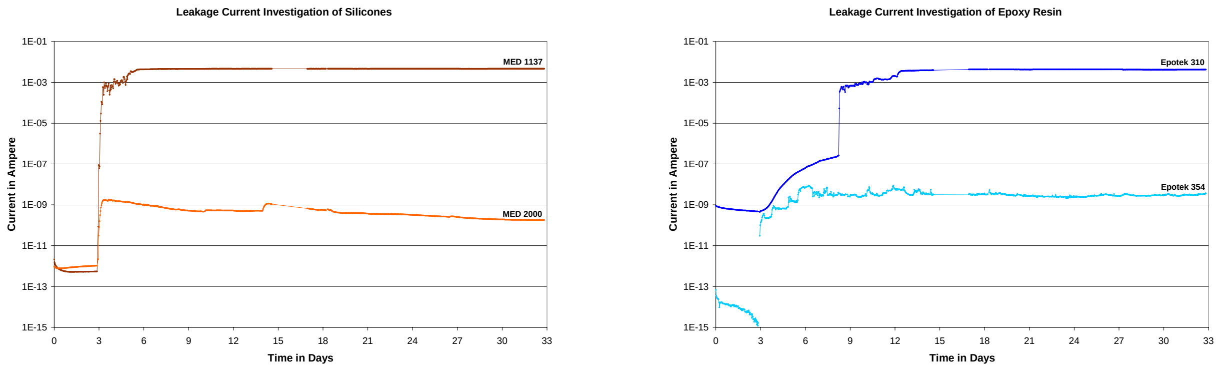


Fig. 11: Typical leakage current test results for the investigated silicones and epoxy resins after 30 days in physiological saline solution.

The peel tests showed a very good adhesion when using a combination of plasma activation of the Si surface and a following application of adhesion promoter. During the tests the adhesion was always better than the cohesion of the film which led to breaks only of the Parylene C layer and not between the polymer and the Si surface (Fig. 12). The tensile strength of the investigated Parylene C foils was lower compared to the literature values, which is in the range of 60 N/mm² to 70 N/mm². The maximum force was about 50 N/mm² (Fig. 13).

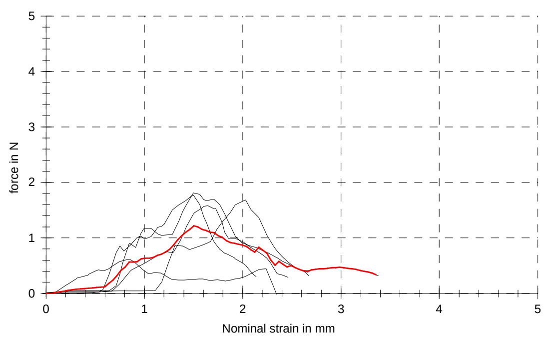


Fig. 12: Stress-strain diagram of peeled off Parylene C on Si. The polymer film broke at the maximum forces.

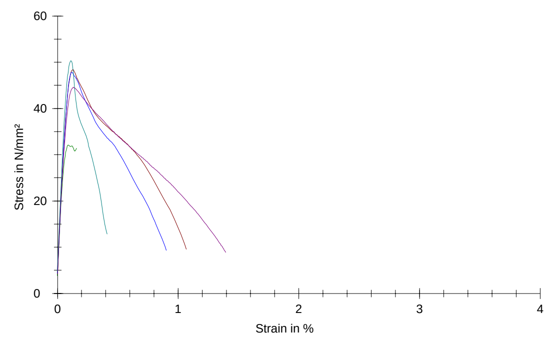


Fig. 13: Tensile strength diagram of peeled Parylene C sheets.

<u>Discussion/Interpretation of results</u>

The new PCB design as well as the new IDE shape enhances the potentials of the leakage current measurement system. The PCB with gold top layer provides a much more precise shape than the older one and the gold metallization provides better connection to the gold contact pins of the multiplexer electronic.

Focus of this first leakage current investigation of the medical grade silicones and epoxy resins was the behaviour of the encapsulation material during prolonged measurement time of 30 days. In relation to the leakage current results the silicone MED 2000 and epoxy resin Epotek 354 showed promising performance to enforce a conformal and consistent encapsulation system with high mechanical stability and better insulation capability.

A potential reason for the lower tensile strength force during the peel test may be the transition between the Parylene film on the glue tape and the silicon surface which can lead to undefined micro shapes with minor tensile strength properties. In addition, insufficient coating parameters for the used amount of Parylene dimer may also lead to inferior film properties.

Future plans for the next (2) quarters

New leakage current samples with the new designed parts will be manufactured and additional tests with other IDE shape designs will be tested to enhance the investigation possibilities of the system. The planned tests for investigations of wet and dry application of silane adhesion promoter will be continued as well as adhesion investigations of medical grade silicones and epoxy resins. We also plan to carry out initial tests with PTFE based encapsulations.

III.b.1 Task 6: Testing and validation of probe systems (in-vitro/in-vivo)

III.b.1.1 Bench testing of interface/electronics

We have completed benchtop testing of the INI1 chip. Our tests show basic functionality in all modules. Our voltage regulator successfully converts an ac voltage on a small off-chip coil into a regulated 3.3 VDC on-chip supply. The regulator requires a minimum peak coil voltage of 5.6 V for proper power supply generation. We are currently powering the chip via a 2.64-MHz wireless link in our laboratory. Command data may be sent to the chip by amplitude-modulating the power waveform. We have sent data at a rate of 6.5 kbit/sec, although we have discovered a bug in our data receiver that leads to prohibitively high bit error rates. The source of this bug is now well understood, and this circuit was corrected in the INI2 chip.

III.b.1.2 In-vivo testing of interface

Description/Rationale

We have evaluated the performance of the Utah wireless telemetry system by periodic recording of cortical neural activity in anesthetized cats. We have implanted Utah Electrode Arrays in or near auditory cortex of a total of three cats, and, as specified in our contract, we have telemetered neurally recorded data twice a week to an external data acquisition system of our own design.

Experimental Results

Prior to recording the telemetered neural data, we have connected either a Cerebus 128-channel data acquisition system or a 100-channel NSAS data acquisition system to the head mounted percutaneous connector as a 'gold standard' for monitoring which electrodes had isolatable units, the amplitude of the units, and the amplitude of the noise recorded on the electrodes. As of this writing, we have successfully telemetered neural data, twice a week, for a total of three weeks. This report describes work in progress, as we have yet to complete the terms of our contract (four weeks of wireless recorded data transmission). We will provide a complete report of the *invivo* evaluation at the end of the four week period. For all recordings, the implanted UEA is wired to a skull mounted percutaneous connector shown below. An interface board is plugged into the percuataneous connector for easier access to each individual electrode.

Discussion/Interpretation of Results

Cat 1: implanted April 12, 2006: Lead wires too short for proper implantation. No units recordable, but percutaneous connector has remained well attached to the animal, with no signs of infection or inflammation post implant up to the time of this writing.

Cat 2: implanted May 17, 2006. Units recorded on Cerebus 3-4 hours post implant. Connector was removed by cat on May 20 or 21 before recordings of telemetered activity could be attempted.

Cat 3: implanted June 8, 2006. First recordings made June 12. Recordings made twice weekly since then.

Fig. 14: Photographs of percutaneous, skull mounted connector on Cat 1

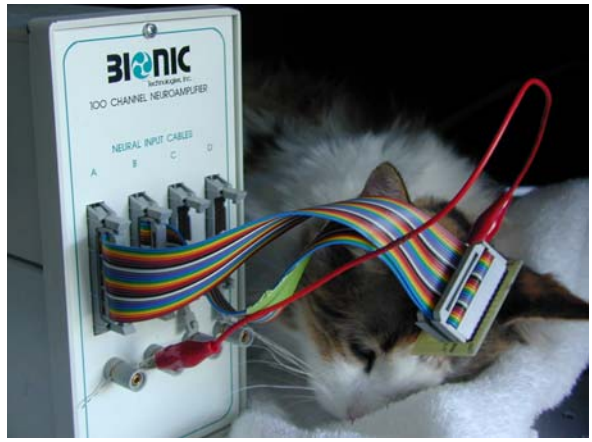


Fig. 15: Connections used to record units with the NSAS/Cerebus system

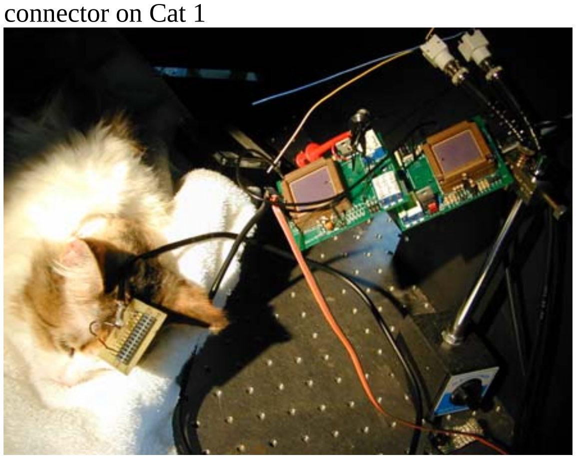


Fig. 16: Connections used to telemeter responses to external electronics

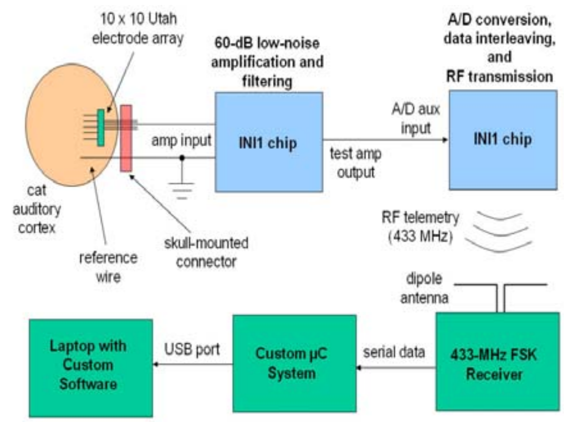


Fig. 17: Block diagram of Utah Wireless Telemetry system

Because of contamination of the analog signals by the digital circuitry on our INI1 chip, the wireless telemetry system was composed of two INI1 chips: one chip (mounted in a large ceramic carrier which was, in tern, mounted in an even larger socket) was used as the neural amplifier, and the amplified signal was sent to a second INI1 chip for digitization and telemetry. The telemetry configuration is illustrated in Fig. 18. Also, because electrode connection to a single INI1 amplifier was made via a single pin on the ceramic connector, only one electrode could be examined at a time (however, all amplifiers on the INI1 chip were powered, and presumably were fully functional).

Timeline of recordings:
Cat 1:

May 17

Cat 3:

June 12, 15, 20, 21, 27, 28, ongoing.

All neural activity was spontaneous in animals that had been anesthetized with Telezol.

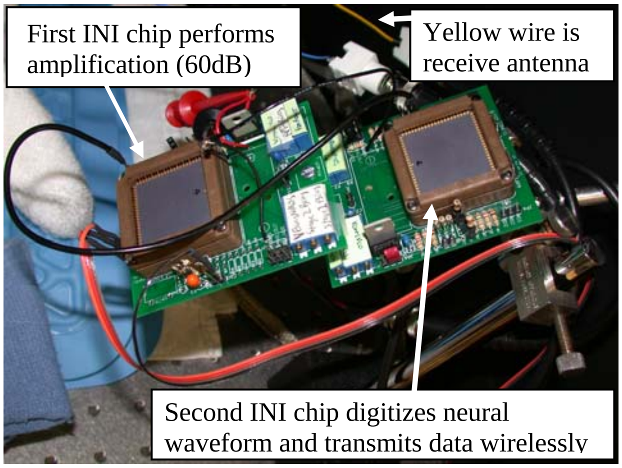


Fig. 18: Close-up photograph of Utah Wireless Telemetry system

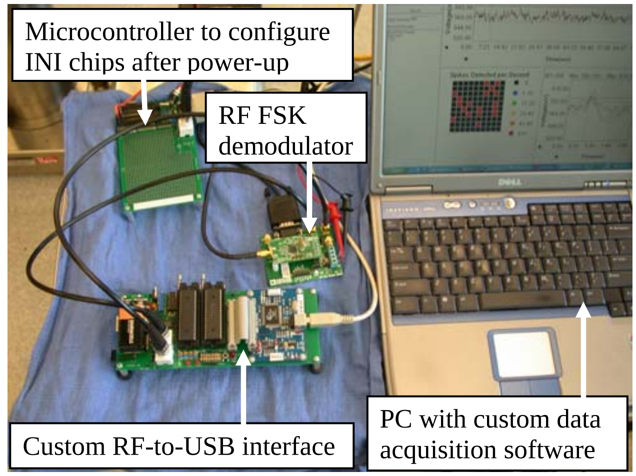


Fig. 19: Close up photograph of microcontroller, RF receiver, RF to USB interface, and data acquisition laptop computer

Specimen recordings:

Telemetered data –Fig. 20Fig. 27 show the units recorded on indicated dates. The left-hand plots show 72 ms of activity with one or more action potentials occurring in the recording period. The right-hand plot shows the kinetics of the action potentials recorded around the recording period but on a faster time base (2 ms). These responses were thresholded (the dotted lines in the 72 ms plots indicate the threshold level).

NSAS recordings – In Fig. 28Fig. 33 two types of plots are presented. One plot shows many superimposed thresholded responses, often with two separable units (the window is 1.6 ms long). The second type of plot shows separated single units recorded on a particular electrode, with superimposed units in the left panel, and a principal component decomposition of the units in a PCA space on the right panel. The lower left panels show the averaged single unit responses and inner-spike interval plots.

Telemetered Single Unit Respones:

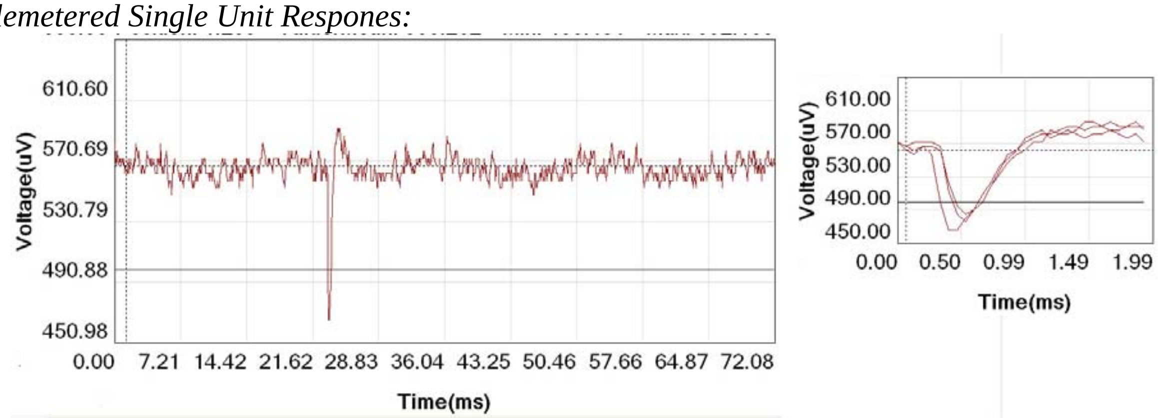


Fig. 20: Neural data wirelessly transmitted from Cat 1 on May 17, 2006

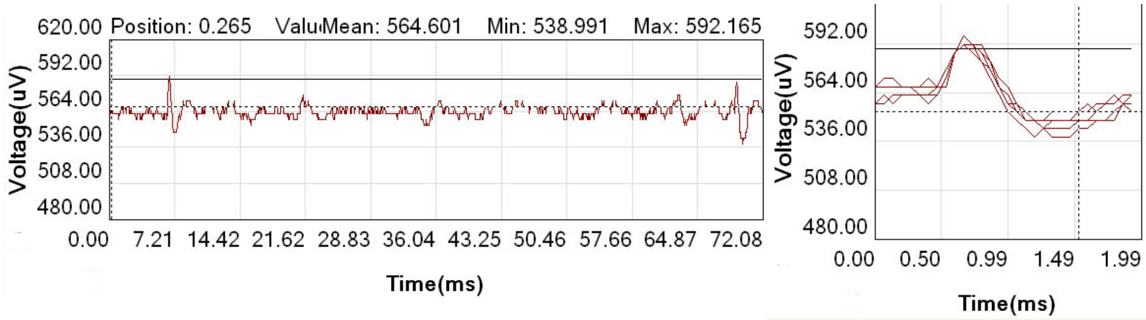


Fig. 21: Neural data wirelessly transmitted from Cat 3 on June 12, 2006

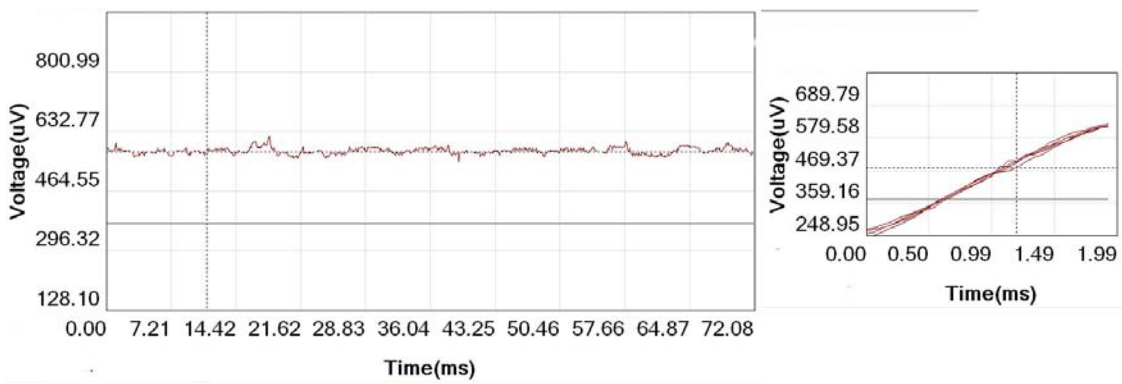


Fig. 22: June 12 ref (To illustrate the noise from our wireless amplifier and recording setup, we have recorded the activity on the reference electrode, a 2mil deinsulated wire implanted subdurally at the implant site)

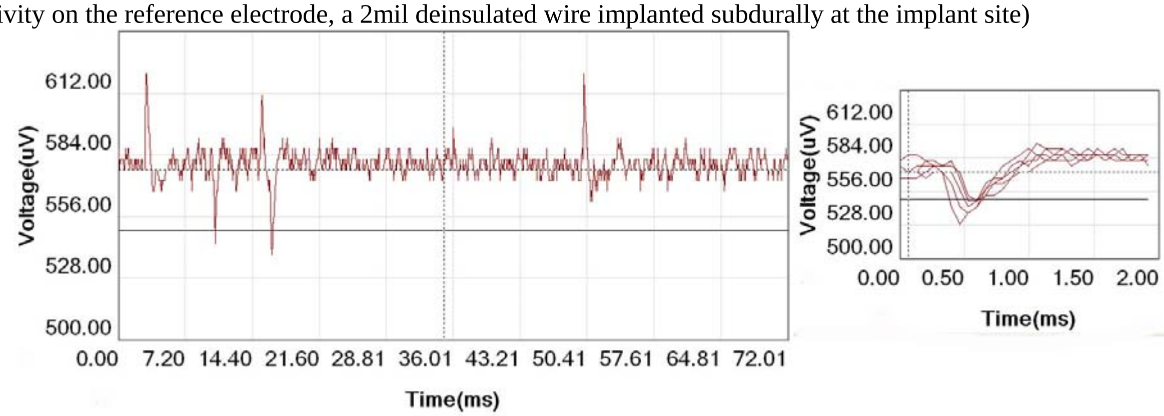


Fig. 23: Neural data wirelessly transmitted from Cat 3 on June 15, 2006

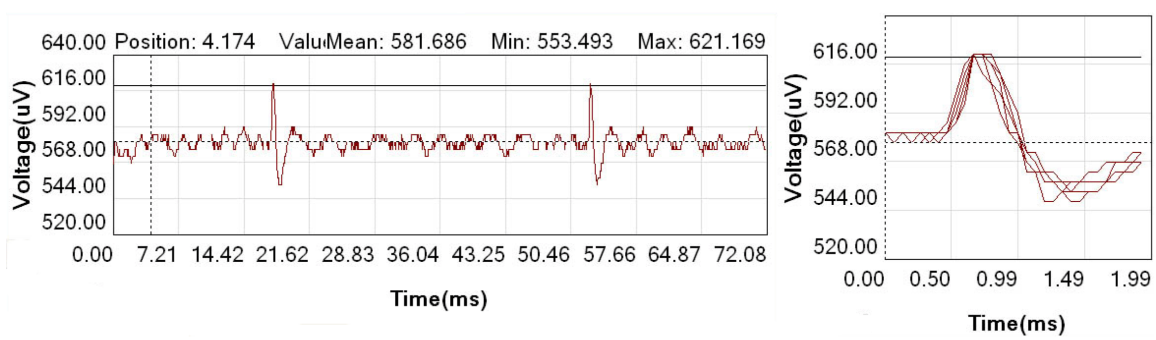


Fig. 24: On June 20, 2006 from Cat 3

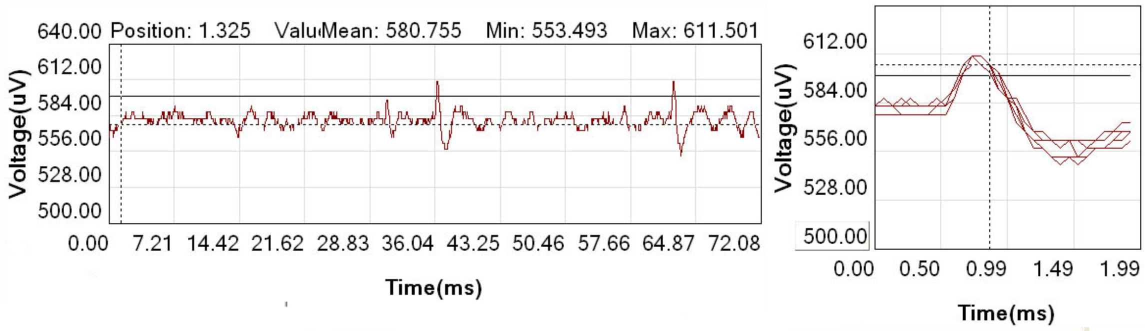


Fig. 25: On June 21, 2006 from Cat 3

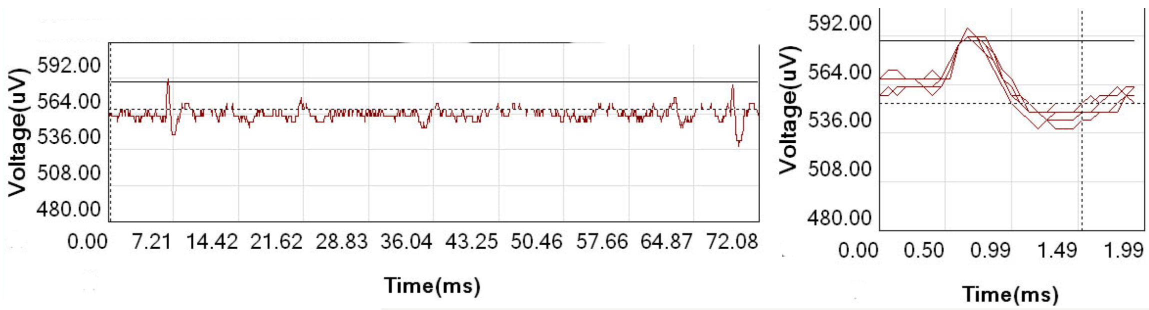


Fig. 26: On June 27, 2006 from Cat 3

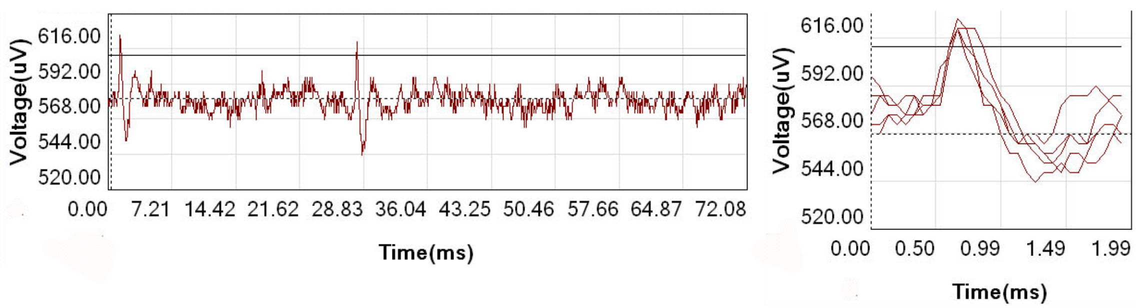


Fig. 27: On June 28, 2006 from Cat 3

Single Unit Responses Recorded With the NSAS Data Acquisition System

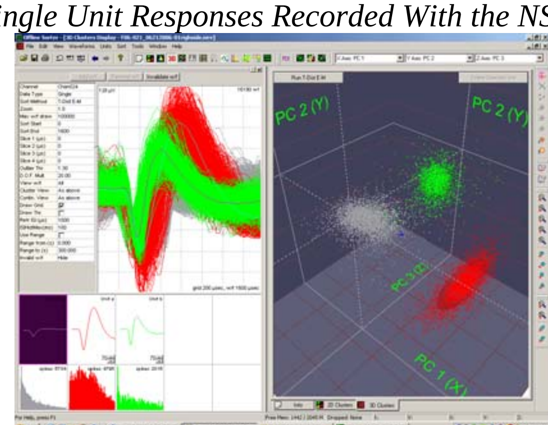


Fig. 28: June 21 screenshot

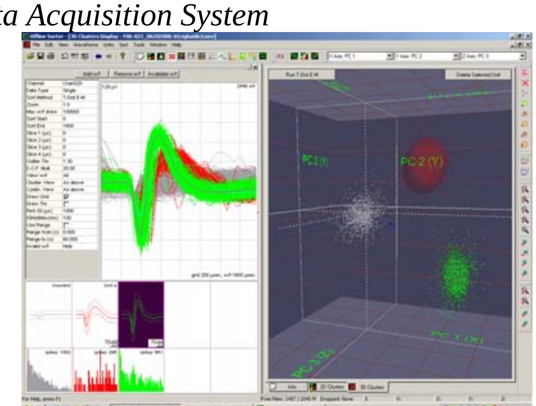


Fig. 29: June 20 electrode 20

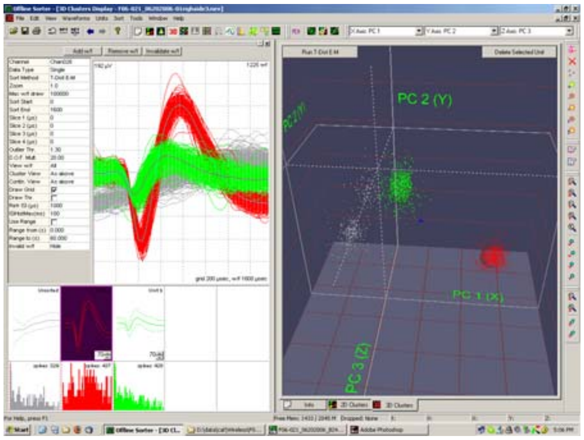


Fig. 30: June 20 electrode 28

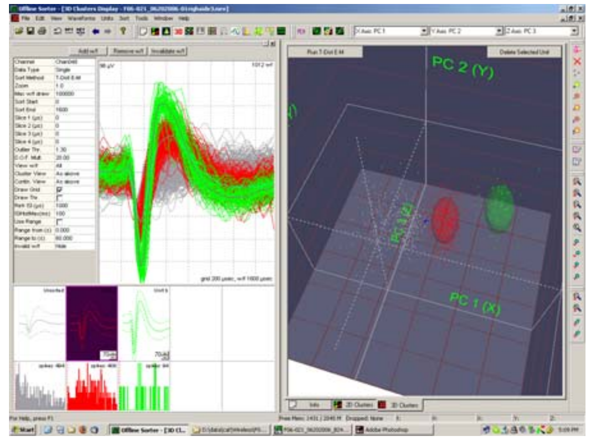


Fig. 31: June 20 electrode 48

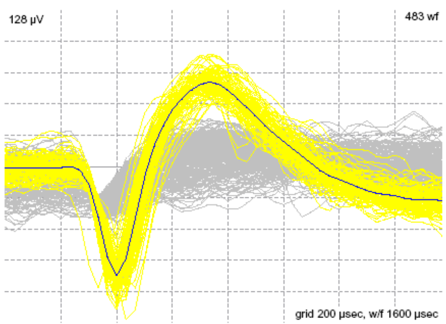


Fig. 32: June 27, 2006

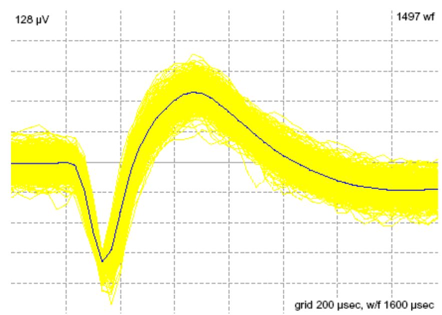


Fig. 33: June 28, 2006

Future plans for the next (2) quarters

Phase I (base contract period): We will continue making recordings from the Cat 3.

Phase II (option I): We will generate statistical data on all processes to confirm reliability and repeatability. We will start to design the INIP3 chip and expect that by summer 2007 we will have fabricated and tested the INIP3. We will conduct phase II cat experiments in fall 2007.

IV. Concerns

During the 7th quarter of the project there was a delay in collecting the neural recordings due to the removal of connector to the implanted array by the cat 2. We believe we can present the required data by July 12th and continue with the project as scheduled.

Salt Lake City, Utah, July 9th 2006

Prof. Dr.-Ing. F. Solzbacher,
Department of Electrical Engineering, University of Utah